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I.E.C. Adopts MKS System of Units

At its plenary meeting of June 1935 at Scheveningen-Bruxelles, the International Electrotechnical Commission unanimously adopted the meter-kilogram-second (mks) or Giorgi system of units, 15 of the 25 constituent countries being represented. In this paper the principal historical antecedents of this action by the I.E.C. are outlined, and its principal import to electrical engineering is indicated. Since the preparation of this paper there have been further important developments in connection with the adoption of this system; reports of these developments, as translated from the original French texts, are given in appendixes I and II.

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As IS WELL KNOWN, the International Electrotechnical Commission is an international organization maintained by 25 countries. It was called into existence under the leadership of R. E. Crompton, in response to a recommendation of the International Electrical Congress of St. Louis (Mo.) in 1904. It was organized in 1906 with its secretariat in London, and C. LeMaistre has been its general secretary since that time. It comprises 24 advisory committees, each dealing with a particular electrotechnical subject, and it has held plenary meetings in London, Paris, Brussels, The Hague, Berlin, Cologne, Turin, Zurich, Bellagio-Rome, Geneva, Denmark, Scandinavia, and New York. It has accomplished much international electrotechnical work during its 29 years of activity.

At its plenary meeting, in June 1935, at Scheveningen-Bruxelles, the I.E.C. unanimously adopted the Giorgi System of meter-kilogram-second (mks) units, 15 countries being represented by the delegates present. Every electrical engineer should make himself acquainted with the significance of this decision. In effect, it replaces the 3 systems at present in use (namely, the absolute electromagnetic cgs system, the absolute electrostatic cgs system, and the practical series) by one practical system.

The fundamental units are so chosen that the present practical series or system becomes at once an absolute system. This brings about a great simplification in the teaching of units and in practical calculations.

For the present, the question of rationalization has been left for future consideration. As the permeability and permittivity of space are no longer unity, it would be an easy matter to fix their values so as to rationalize all calculations; that is to say, to arrange matters so that the multiplier 4π comes into those formulas only where it would be expected to enter.

Not since the International Congress of Electricians, at Paris[7] in 1881, has there been made a decision of similar international significance. It is the purpose of this paper to outline the principal historical antecedents of this I.E.C. action, to indicate its main import to electrical engineering, and to suggest a few of the implications it may involve. The account here given is, however, necessarily subsidiary to the official minutes of the meeting, which should be consulted by interested readers.

History of CGS and Practical Units

As early as 1848, resistance boxes had been produced in Germany, calibrated to correspond to the linear resistance of particular sizes of telegraph wire. Gauss and Weber, about 1850, showed how to make certain electric and magnetic measurements in absolute measure, adopting for this purpose the millimeter-milligram-second system (mms). In 1860, Werner Siemens introduced his mercury unit of resistance; i. e., a glass tube of one square millimeter cross sectional area and one meter long, filled with pure mercury, at zero degrees centigrade.

The British Association for the Advancement of Science (commonly abbreviated to B.A.), at its meeting in Manchester, of 1861, established a committee to report upon "standards of electrical resistance." This B.A. committee became famous for its pioneer work. It made annual reports[1] until 1867. It recommended the adoption of an absolute fundamental system of scientific units, and after trying the foot-grain-second system (fgs) advocated the meter-gram-second system (mgs). It computed theoretically, and worked out practically, approximate electric standards, especially that of electrical resistance, for which Latimer Clark suggested the name *ohm*. Because the mgs absolute electromag-

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7. For all numbered references see list at end of paper.

netic unit of resistance was found to be an extremely small quantity in reference to practical needs, this committee recommended that the practical unit of resistance (or *ohm*) should be 10^7 of these units, since 10 such *ohms* would be roughly equal to the resistance of one mile of an ordinary size of telegraph wire. Telegraph engineering was at that date almost the only existing application of electrical science. The demand for electrical units came from telegraph engineers. Again, since the mgs electromagnetic unit of electromotive force was extremely small from a telegraph-engineering standpoint, another large decimal multiple, 10^5, was recommended for the practical unit, with the name *volt*, since about 100,000 such mgs units were roughly equal to the electromotive force of one Daniell voltaic cell. The decimal factors 10^7 and 10^5 were purely arbitrary and adventitious, to meet the needs and convenience of these particular applications; but once the *volt* and *ohm* were adopted, a new strong influence came into effect, namely, systematic connection between the practical units, such, for example, that the *volt* acting in a circuit of one *ohm*, should deliver one practical unit of current. This would mean that the rest of the practical units were no longer arbitrary, but assigned themselves in accordance with the laws of physics, in one-to-one unit relations. Thus the literature shows that the original value of the *farad*, as the B.A. practical unit of capacitance, was equal to what now is called the *microfarad*, taken as an arbitrary convenient magnitude for telegraph practice; but this was changed[2] later to the present magnitude of the *farad*, because of considerations of systematic relations.

The second B.A. committee was appointed in 1868, "for the selection and nomenclature of dynamical and electrical units." It proceeded to discuss and compare the relative advantages of the cgs, mgs, fgs, and mms systems, for the purposes of a comprehensive fundamental system adapted for use in all branches of science. Its first report—an important document—was published[3] in 1873. It decided, after much debate, in favor of the cgs system. A principal reason for this choice was that the cgs system was the only one of the 4 considered that gave the unit of density equal to that of pure water at standard temperature and pressure (one gram per cubic centimeter). The practical units with standards already in use among practitioners—*ohm*, *volt*, and *farad*—were converted from the mgs multipliers 10^7, 10^5, and 10^{-7}, to the corresponding cgs multipliers 10^9, 10^8, and 10^{-9}, as they exist today. The report also advocated 3 names for as many cgs units, namely, the *dyne* for unit force, the *erg* for unit work, and the *erg per second* for unit power. These names also remain in use.

Although the cgs system and its appended practical units gained recognition among scientists and electrotechnicians, no international action was taken on them until the First Electrical Congress at Paris, in 1881. This memorable congress[7] adopted the cgs electromagnetic units as fundamental, and 5 practical units decimally derived therefrom: the *ohm*, *volt*, *ampere*, *coulomb*, and *farad*. Steps were taken to produce a standard *ohm* as a mercury column resistor of one square millimeter cross section at standard temperature and pressure. The 5 practical units formed a series in one-to-one relation. The cgs system thus became the great fundamental absolute system for universal measurements in all branches of physical science.

Since 1881, 4 more units have been added to the practical electrical series: the *joule*, *watt*, *henry*, and *weber*, in 1889, 1889, 1893, and 1933, respectively, the first 3 at international electrical congresses, and the fourth by the I.E.C. at Paris (confirmed this year at Brussels).

Glossary of Abbreviations

I.E.C.	International Electrotechnical Commission
B.A.	British Association for the Advancement of Science
I.P.U.	International Union of Pure and Applied Physics
S.U.N. committee	Committee on symbols, units, and nomenclature of the I.P.U.
N.P.L.	National Physical Laboratory (British)
E.M.M.U. committee	Electric and magnetic magnitudes and units committee of the I.E.C.
I.C.W.M.	International Committee of Weights and Measures
C.C.E.	Comité Consultatif d'Electricité of the I.C.W.M.
mks	meter-kilogram-second (system)
cgs	centimeter-gram-second (system)
fgs	foot-grain-second (system)
mgs	meter-gram-second (system)
mms	millimeter-milligram-second (system)
qes	(earth-quadrant)-(eleventh-gram)-second (system)
cg-ss	centimeter-(gram-seven)-second (system)

Comprehensive Practical Unit Systems

Clerk Maxwell, who placed the classical cgs systems (electric and magnetic) on a firm mathematical basis, pointed out,[6] in 1881, that the practical series of electromagnetic units virtually formed a complete electromagnetic system, in which the unit of length was the earth-quadrant (10^9 centimeters), the unit of mass 10^{-11} gram (eleventh-gram), and the unit of time the mean solar second. The numerical value of space permeability in this qes system of Maxwell was $\mu_0 = 1$, the same as in the cgs magnetic system. This conception of the practical series as part of a magnetic system was interesting, but merely a proposition in the theory of units. Neither Maxwell nor any other theorist ever seriously proposed that the qes system should be adopted in practical scientific work, because the fundamental units of length and mass were so awkward. For instance, with unit electric current strength as one *ampere*, the unit of current density would be the *ampere per square earth quadrant!* Maxwell's discovery remained, therefore, an academic curiosity.

G. Giorgi of Rome pointed out,[12] in 1901, that if the value of space permeability μ_0 were taken not as unity but as 10^{-7} unrationalized, or as $4\pi \times 10^{-7}$ rationalized, the practical series fell into an electromagnetic system like the qes system, and parallel to the magnetic cgs system, with unit length equal to the international meter (10^2 centimeters), unit mass equal to the kilogram, and unit time the mean solar second. Giorgi presented a paper on this new

mks system to the International Electrical Congress[15] of St. Louis, in 1904. A colleague of his, Ascoli, presented another paper[14] to the St. Louis congress, pointing out that there existed an indefinitely long series of such systems, all containing the practical series of units, such that if the system length unit were 10^l centimeters and its mass unit 10^m grams: then the equation of condition was $2l + m = 7$. In Giorgi's mks system, $l = 2$ and $m = 3$: while in Maxwell's qes system, $l = 9$ and $m = -11$. In this indefinite series of possible systems, all embracing the internationally adopted practical units, only Maxwell's qes system kept $\mu_0 = 1$, and only Giorgi's mks system comprised the international standards of length and mass maintained by the International Bureau of Weights and Measures at Sèvres, in the Park of St. Cloud, near Paris. Moreover, only Giorgi's mks system offered units of length and mass that were satisfactory practically.

The Giorgi mks system slowly advanced in favor all over the world. It was endorsed by several physicists in Europe. In the United States, G. A. Campbell came forward[24] heartily in support of the "definitive system," which differs from the Giorgi system only in details of definition. The only seriously advanced objection to it, setting aside the complaint that the Giorgi system fundamental equations are dissymmetrical from the standpoint of theoretical physics, seems to have been that its unit of density is the kilogram per cubic meter, which is 1,000 times smaller than that of pure water under standard specifications. Since the recent discoveries, however, of deuterium and of "heavy water," the argument for unit-density water has lost some force. To have the density of distilled water unity is, of course, an asset to a system of units; but its loss is not disastrous. The great bulk of water on the earth is ocean water, with a density distinctly greater that that of one gram per cubic centimeter; moreover, tables of specific gravity with that of pure water taken as unity are the same in the mks system as in the cgs system, and for engineering purposes specific gravities are likely to be more useful than absolute densities.

In or about the year 1916, proposals appeared to adopt another comprehensive system, sometimes[21] called "international system," based upon the centimeter as length unit, the gram-seven or 10^7 grams (10 metric tons) as mass unit, and the mean solar second as the unit of time (cg-ss system). Here $l = 0$ and $m = 7$. Several proponents have been named for this system, among them Blondel, Dellinger, Bennett, Karapetoff, and Mie. In the cg-ss system, the numerical value of space permeability μ_0 would be 10^{-9} unrationalized, and $4\pi \times 10^{-9}$ rationalized. Various papers and at least one book[22] have been printed on this system, which claimed many of the advantages of the Giorgi system. Its principal disadvantage, however, was the awkwardly large size of its unit of mass.

Magnetic Units

In reference to the history of practical magnetic units, it may suffice here to point out that as early as 1889, the Second Electrical Congress of Paris discussed the adoption of units for magnetic flux and flux density in the practical system, with personal names for both; but no action was taken in the matter at that time. Similar suggestions were made at the Third International Electrical Congress, of Frankfort, in 1891, but again without action being taken. At the Fourth International Electrical Congress, of Chicago, in 1893, certain proposals of the A.I.E.E., to adopt magnetic units in the practical series for magnetomotive force, flux, flux density, and reluctance, were considered; but the chamber of delegates recommended[9] that magnetic units should be restricted to the cgs system, and without specific names.

At the Fifth International Electrical Congress, of 1900, in Paris, names were requested for cgs magnetic units. There was considerable difference of opinion, and debate. Finally, the congress adopted the names *maxwell* for the cgs unit of magnetic flux, and *gauss* for the cgs unit of magnetizing force H. There was also some accidental misunderstanding of the action taken, some of the delegates present having supposed that the name *gauss* had been adopted for flux density B. No further international action on magnetic units took place thereafter, until the matter was taken up in 1927 by the I.E.C.

Actions of the I.E.C. and the International Union of Pure and Applied Physics (I.P.U.), in Reference to Magnetic Units. At its Bellagio[25] meeting in 1927, the I.E.C. discussed certain proposals relating to magnetic units. In view of much manifest difference of opinion, a subcommittee was appointed to consider and report upon the subject. The committee, composed of representatives from different countries, endeavored to reach conclusions by correspondence; but this was found to be impracticable because of the marked differences of opinion as to the meaning of terms used in magnetic literature and especially as to the meaning of the unit name *gauss*. These differences affected not only the literature of different countries, but also of different writers in each of several countries. The matter therefore was brought to the attention of the various I.E.C. national committees and placed on the agenda of the next I.E.C. meeting, in Scandinavia (1930).

After considerable discussion in Copenhagen and Stockholm, the committee decided unanimously[28] that, for electrotechnical purposes, the convention should be established that in free space the quantities flux density B and magnetizing force H should be taken as physically different; so that their ratio, the space permeability μ_0, was a physical quantity with dimensions and not a mere numeric. The same convention was applied to the absolute permeability μ of a simple magnetic medium; so that its relative permeability μ/μ_0 was dimensionless, or a mere numeric. The committee then assigned the unit name *gauss* to flux density B, confirmed the name *maxwell* for magnetic flux Φ, and gave the new international name *oersted* to the unit of magnetizing force H, all in the classical cgs system. These recommendations were confirmed unanimously by the I.E.C. plenary convention at Oslo, in July 1930. This Oslo convention gave satisfaction to the great

Table I—Incomplete List of MKS Units and of Corresponding CGS Units

No.	Quantity	Symbol	MKS Unit	CGS Unit	CGS Units in One MKS Unit
Mechanical					
1	Length	L	meter	centimeter	10^2
2	Mass	M	kilogram	gram	10^3
3	Time	T	second	second	1
4	Area	S	square meter	square centimeter	10^4
5	Volume	V	cubic meter (stere)	cubic centimeter	10^6
6	Frequency	f	hertz (cycle per second)	cycle per second	1
7	Density	d	kilogram per meter	gram per cubic centimeter	10^{-3}
8	Specific gravity		numeric	numeric	1
9	Velocity	v	meter per second	centimeter per second	10^2
10	Slowness		second per meter	second per centimeter	10^{-2}
11	Acceleration	a	meter per second per second	centimeter per second per second	10^2
12	Force	F	—— (joule per meter)	dyne	10^5
13	Pressure	p	—— (joule per cubic meter)	dyne per square centimeter, barye	10
14	Angle	α, β	radian	radian	1
15	Angular velocity	ω	radian per second	radian per second	1
16	Torque	τ	—— (joule per radian)	dyne $\perp$ centimeter	10^7
17	Moment of inertia	J	kilogram-square meter	gram-square centimeter	10^7
Energetics					
18	Work or energy	W	joule	erg	10^7
19	Angular work, $\tau\alpha$	W	joule	erg	10^7
20	Volume energy	w	joule per cubic meter	erg per cubic centimeter	10
21	Active power	P	watt	erg per second	10^7
22	Reactive power	jQ	var	erg per second	10^7
23	Vector power, $P \pm jQ$		watt $\angle$	erg per second	10^7
Thermal					
24	Quantity of heat	Q	kilogram-calorie	gram-calorie	10^3
25	Temperature	θ	degree centigrade or Kelvin	degree centigrade or Kelvin	1
Luminous					
26	Intensity	I	candle	candle	1
27	Luminous flux	ψ	lumen	lumen	1
28	Illumination	E	lux	phot	10^{-4}
29	Brightness	b	candle per square meter	stilb	10^{-4}
30	Focal power		diopter		10^{-2}
Electrical					
31	Electromotive force	E	volt		10^8
32	Potential gradient	$\mathcal{E}$	volt per meter		10^6
33	Resistance	R	ohm		10^9
34	Resistivity	ρ	ohm-meter		10^{11}
35	Conductance	G	siemens, mho		10^{-9}
36	Conductivity	γ	siemens per meter, mho per meter		10^{-11}
37	Reactance	jX	ohm		10^9
38	Impedance, $R \pm jX$	Z	ohm $\angle$		10^9
39	Quantity	Q	coulomb		10^{-1}
40	Displacement	Q	coulomb		10^{-1}
41	Current	I	ampere		10^{-1}
42	Current density	i	ampere per square meter		10^{-5}
43	Capacitance	C	farad		10^{-9}
44	Specific inductive capacity	ϵ/ϵ_0	numeric	numeric	1
Magnetic					
45	Magnetic flux	Φ	weber	maxwell	10^8
46	Flux density	B	weber per square meter	gauss	10^4
47	Inductance	L	henry		10^9
48	Relative permeability	μ/μ_0	numeric	numeric	1

NOTE: Various units used in acoustical engineering, radio engineering, and mechanical engineering are omitted from this list.

majority of electrotechnicians all over the world; but the satisfaction among physicists has been less complete.

The International Union of Pure and Applied Physics (I.P.U.), at its Brussels meeting of July 1931, appointed, for the first time, a committee on "symbols, units, and nomenclature" (S.U.N.). This important S.U.N. committee has held several meetings of great value to the physical sciences. Its president has been Sir Richard Glazebrook, and its secretary, E. Griffiths, of the National Physical Laboratory (N.P.L.). The I.E.C. requested the I.P.U. for the co-operation of the S.U.N. committee in the matter of magnetic units, and this co-operation very courteously was granted. The S.U.N. committee proceeded to prepare a questionnaire on "electrical units," addressed to physicists and physical societies in different countries, calling attention to certain ambiguities in the definitions of fundamental electric and magnetic quantities entering into the classical cgs system, and inviting opinions as to how these ambiguities might be eliminated, in order to arrive at international agreement. This printed document[40] was issued by the S.U.N. committee in December 1931, and replies thereto were collected and distributed to the I.P.U. committees, as well as to the national committees of the I.E.C.

The electric and magnetic magnitudes and units (E.M.M.U.) committee of the I.E.C. met in London, September 1931, to consider the Oslo recommendations made by the same committee in July 1930. Ten countries were represented by delegates. The president and secretary of the S.U.N. committee attended the meeting, as well as H. Abraham

(general secretary of the I.P.U.), President Enström, and General Secretary LeMaistre of the I.E.C. At this meeting the actions taken at Oslo in regard to cgs magnetic units were endorsed unanimously.

In view of the many physicists assembling in Paris during the week July 5–12, 1932, to attend the 1932 Paris International Electrical Congress, the S.U.N. committee called an informal meeting in Paris on July 9, to discuss the matters contained in its questionnaire, and especially the cgs magnetic units. President Sir Richard Glazebrook was the chairman, and E. Griffiths was the secretary; 19 persons, from 8 countries, attended. The actions taken were informal, in the sense that the voting was by individuals and not by countries. The resolutions adopted, if not unanimous, were by considerable majorities. Among the resolutions was the proposition (6) "B and H are quantities of different nature." The Oslo convention was endorsed, and the I.E.C. actions concerning cgs magnetic units and their names, were confirmed. No specific reference was made to the Giorgi system; but it was voted that: "(1) Any system of units recommended must retain the 8 internationally recognized practical units: *joule, watt, coulomb, ampere, ohm, volt, farad, henry.*" It was voted also that in any practical magnetic system, "the factor $4\pi/10$ should be retained in the definition of magnetomotive force." This implies that the S.U.N. committee opposed rationalizing the practical magnetic system.

At the Brussels meeting of the I.P.U. in July 1931, already mentioned, R. A. Millikan was elected as the incoming president, and it was contemplated holding the next I.P.U. meeting in Chicago, June 1933, contemporaneously with the Chicago exposition of 1933. It was found necessary, however, to postpone the I.P.U. meeting; but a meeting of the American Section of the I.P.U., with a few foreign guests, was held at Chicago instead, June 24, 1933, in Mandel Hall, University of Chicago. R. A. Millikan, president of the I.P.U., opened the meeting. The program was directed to the work of the international S.U.N. committee, and 6 papers were read, with E. C. Crittenden, chairman of the American S.U.N. committee in the chair. The papers[49] related to electric and magnetic units and systems, as prepared by R. T. Glazebrook, H. Abraham, L. Page, G. A. Campbell, H. L. Curtis, and A. E. Kennelly. E. Bennett acted as secretary of the meeting. The attendance at the meeting was about 150, and of these the estimated number voting was 30 to 40. In brief, the following resolutions[49–53] were passed:

1. That the classical cgs system should be left unchanged.

2. That the existing series of practical units may advantageously be extended into a complete absolute practical system, either through the mks system, or through the cg-ss system; of these, the mks system is preferred.

3. That the American S.U.N. committee shall be requested to consider the objections to the use of the absolute ohm and the advantage that might be gained by the use of the international ohm in the practical system.

A meeting of the E.M.M.U. committee of the I.E.C. was held[54] at Paris in October 1933. The *weber* was adopted as the practical unit of magnetic flux Φ, subject to the approval of the various national committees. The names *hertz* and *siemens* likewise were voted, for the names of the practical units of frequency and conductance, respectively. The Oslo convention concerning μ_0 and μ was reconfirmed. Special consideration was given to the resolutions passed by the American Section of the I.P.U. at Chicago in June 1933, on the extension of the practical series of units into a complete system, as referred to in preceding paragraphs. Giorgi, who was present as an Italian representative, gave a brief résumé of the mks system. H. Abraham, general secretary of the I.P.U., who attended the meeting, pointed out certain advantages of the mks system, as also did M. Brylinski, president of the French I.E.C. national committee. The following resolution was adopted unanimously:

"Section B of the advisory committee No. 1 on nomenclature, having heard with great interest the communication from Mr. Giorgi on the mks system, and endorsing the resolution adopted by the American Section of the International Union of Pure and Applied Physics at Chicago, in June 1933, decides to invite the national committees to give their opinion on the extension of the series of practical units at present employed in electrotechnics by its incorporation in a coherent system having as fundamental units of length, mass, and time, the meter, kilogram, and second, and as fourth unit either that of resistance expressed as the precise multiple 10^9 of cgs electromagnetic unit or the corresponding value of the space permeability of a vacuum."

These resolutions were distributed to all the I.E.C. national committees in the regular way, together with the minutes of the meeting, with a request for opinions.

Actions of the I.E.C. at the Latest and Plenary Meeting in Scheveningen-Brussels

In regard to actions on units, the E.M.M.U. committee met at Scheveningen, with representatives from 15 countries. President Enström attended the sessions. Paul Janet, president of advisory committee No. 1, was prevented from being present. He was unanimously elected honorary president of the I.E.C., an honor shared by Elihu Thomson. The principal actions taken at this meeting were briefly as follows:

1. The Oslo convention concerning μ_0 and μ was reconfirmed.

2. The adoption of the *weber* was confirmed as the name of the practical unit of magnetic flux Φ.

3. The replies were read as received from the various national committees concerning the extension of the practical series into a practical system of units, on the mks basis. Practically all the replies were in favor. The question of adopting the mks system then was moved and unanimously approved, except that 2 countries made reserves as to the suitability of retaining the *kilogram* as a basic unit of the system.

There was considerable difference of opinion among the delegates as to the fourth fundamental unit for the system. The *ohm* and the *coulomb* each had been suggested. It was agreed that a fourth unit was needed, because it would be possible, starting with the 3 units, meter, kilogram, and second, to construct an indefinite number of possible associated electromagnetic series, differing from the existing practical series which all desired to maintain. It finally was agreed to defer action on the choice of a fourth fundamental unit until an opportunity had been offered to consult the Comité Consultatif d'Electricité (C.C.E.) of the International Committee of Weights and Measures (I.C.W.M.) at Sèvres, and

also the S.U.N. committee of the I.P.U. In the meantime, it was voted that the new system should be called the "Giorgi System." Opinions also were requested from the various national committees as to the selection of the fourth unit.

4. By way of example, in the formation of derived units in the system, the following were adopted unanimously: (*a*) the volt per meter as unit of electric force; (*b*) the weber per square meter as unit of magnetic flux density B; (*c*) the joule per cubic meter as unit of volume energy.

5. The actions taken at the preceding meeting in Paris, concerning the practical unit names *hertz* and *siemens* were confirmed, as also the desirability of inserting the space permeability symbol μ_0 in all working magnetic formulas where its absence might mislead, thus reconfirming the Oslo convention.

Advantages of the Giorgi System to Students of Electrical Engineering

Table I, which gives a list of mks and cgs units, shows that although the classical cgs system in no way is altered or disturbed by the completion of the practical series into an independent practical system; yet:

1. There is great simplification in elimination of the necessity of learning the decimal ratios 10^9, 10^8, 10^7, 10^{-1}, and 10^{-9}, which connect various units in the 2 systems. The practical units all stand in unity-sequence relation.

2. The mks system is single and requires no accompanying companion electrostatic system. All electrostatic phenomena can be dealt with very easily through the existing electromagnetic practical units.

3. The dimensional formulas of the Giorgi units can be expressed without resorting to fractional exponents, as shown by Giorgi[55] and other writers.

4. It permits the use of either "rationalized" or "unrationalized" formulas, according to the choice of each writer, without disrupting the system on that account.

5. It requires no appreciable change in the existing literature and terminology of electric circuits. It may be said that the electrical engineering literature of the voltaic circuit is already Giorgian. It will not be difficult to transform the literature of the magnetic circuit from cgs to mks units.

6. For almost all practical purposes, the mks system can be studied and used now, without waiting for the formal adoption of the fourth fundamental unit to complete the system's base. Until readers become familiar with the expression of magnetic circuit formulas in mks units, the old cgs magnetic formulas may be retained in the cgs system without confusion.

7. It affords a clear perspective of the distinction between the earlier cgs units and the practical units, in regard to nomenclature and scope. If new cgs units be named, the names may conformably be impersonal. New practical units may conformably receive personal names, especially units 12, 13, and 16 in table I. If desired, a few impersonal names in the mks system might be changed later into personal names.

Comments

Table I shows that the only department of the cgs system in which personal names appear is that concerning the magnetic circuit. This discrepancy results from the resolution of the Chicago congress of 1893 to keep magnetic units out of the practical series. The very large aggregate number of electrotechnicians all over the world thus were impelled to seek for the magnetic circuit names they so earnestly desired, in the cgs system itself. Although this inconsistency is regrettable, it seems likely that with patience and good-will, it may be surmounted later.

Looking back upon the path of the development of units since 1861, when the B.A. made the first move in the direction of practical units, it appears that starting in about 1865 with the *ohm* and the *volt* based upon the cgs system, and with magnitudes selected fortuitously to suit the convenience of electric telegraphy, Ohm's law pointed the way from these 2 nuclei to the coherent magnitude of the *ampere* as the practical unit of current. These, in turn led, through other simple physical laws and their mathematical formulas, to the succeeding members of the practical series. After the *ohm* and *volt*, no further arbitrary choice was left, and the practical series determined itself. Each new member of the series made systematization more imperative and finally led to the completion of the whole series into the Giorgi system. It has been as though the marvelous simplicity of the physical universe in its individual actions, working on the minds of men engaged in physical applications, brought pressure upon them psychologically to imitate in their thoughts and arithmetic the order and system of the vast environment in the physical world. In 1935, the need for the system has reached the stage of international recognition, over a journey of 70 years. Under unfavorable conditions, the time required might have been much greater.

Table I also suggests the importance of co-operation among all scientific organizations, national as well as international, to maintain the systematic quality and classification of all units they employ. In a structure like the mks system there logically can be one and only one unit for each physical quantity.

In regard to the rationalization or nonrationalization of the mks system, discussions on the subject in recent years by the I.E.C. and I.P.U. committees have shown that there is much difference of opinion on the subject. In the E.M.M.U. committee, a small majority has been in favor of rationalization; in the S.U.N. committee, the majority has been more definitely against it. It is clear that any attempt to force a decision one way or the other at the present time would divide the mks adherents

Table II—Electric and Magnetic MKS Units Affected by the Deferred Question of Rationalization

No.	Quantity	Symbol	Name of Rationalized* MKS Unit	Unrationalized Units in One Rationalized Unit
Electrical				
49	Electric flux	ψ	coulomb	
50	Flux density	D	coulomb per square meter	
51	Space permittivity	ϵ_0	farad per meter	
52	Space elasticity	σ_0	meter per farad	
53	Elastance	S	daraf	
Magnetic				
54	Magnetomotive force	$\mathfrak{F}$ or M	ampere-turn	4π
55	Magnetizing force	H	ampere-turn per meter	4π
56	Space permeability	μ_0	henry per meter	$1/4\pi$
57	Space reluctivity	ν_0	meter per henry	4π
58	Permeance	$\mathcal{P}$	weber per ampere-turn	$1/4\pi$
59	Reluctance	$\mathcal{R}$	ampere-turn per weber	4π
60	Pole strength	m	weber	$1/4\pi$
61	Magnetic moment (ml)	$\mathfrak{M}$	weber-meter	$1/4\pi$
62	Magnetization	$\mathfrak{J}$	weber per square meter	$1/4\pi$

* No names have been chosen for unrationalized units.

Table III—Numerical Values of Space Constants in MKS System, Rationalized and Unrationalized

No.	Quantity	Symbol	Rationalized	Unrationalized
Electrical				
51	Permittivity	ϵ_0	$10^7/4\pi c^2 = 8.854 \times 10^{-12}$	$10^7/c^2 = 1.113 \times 10^{-10}$
52	Elastivity	σ_0	$4\pi c^2/10^7 = 1.129 \times 10^{11}$	$c^2/10^7 = 8.988 \times 10^9$
Magnetic				
56	Permeability	μ_0	$4\pi \times 10^{-7} = 1.257 \times 10^{-6}$	10^{-7}
57	Reluctivity	ν_0	$10^7/4\pi = 0.7958 \times 10^6$	10^7

The value of the transmission velocity c is taken here as 2.998×10^8 meters per second and of c^2 as 8.988×10^{16} (meters per second)^2.

Because of admitted small discrepancies, of a few parts per myriad, between certain existing unit standards and their estimated absolute theoretical values, the future adoption of a fourth fundamental unit to complete the base of the mks system, might alter slightly some of the numerical "constants" in Table III.[55]

into 2 opposing camps, the rationalists and the nonrationalists. It seems desirable, therefore, to avoid the issue and to leave each writer free to follow his own choice, until experience may have crystallized opinion in the different countries. The same question pervades the cgs world today. The classical cgs electric and magnetic systems of Maxwell are unrationalized, while the Heaviside-Lorentz modification is rationalized. The advantages of rationalizing would be that the mks system thus would be made simpler, more logical, and coherent. There is much to be said for having pole strength identical with magnetic flux, so that a pole of one *weber* would give emergence to one *weber* of flux, and a charge of one *coulomb* also give emergence to one *coulomb* of electric flux. Table II shows that there are already enough practical international quantities to give names to all the principal units in the rationalized magnetic circuit, although some of them are cumbersome; whereas it appears to be necessary to adopt a series of new international names, in order to provide for the corresponding needs of the unrationalized circuit. Giorgi himself, in proposing his system (1901–04), rationalized it, as an act of recommendation. On the other hand, the disadvantage of rationalizing the mks system would be to break parallelism, in this direction, with the parent classical cgs system.

As regards the fundamental basis of the mks system, it has been pointed out by several writers that it is a blemish on the system to have (in the *kilo*gram) a basic *prefixed* unit. The mks *meter* is certainly preferable to the cgs *centimeter* in this respect; but the mks *kilogram* is inferior to the cgs *gram*. Theoretically, the basic units of any system should be prefix free. However, the cgs system has given splendid service to the world of science for many years, in spite of the *centimeter*.

Until there has been time to obtain the opinions of the I.C.W.M. and the I.P.U. on the question of choosing the fourth fundamental unit for the mks system, it would be invidious to offer any views on that point. It may be permissible to point out at this time, however, that whatever particular fourth unit may be selected in drawing up the international constitution of the Giorgi system, it is very desirable that each and all of the practical units in the ohm-volt-ampere series shall be identical for both basic and applied physicists. It surely would be a great misfortune to the whole scientific world if in taking up a standard ohm coil, or a standard capacitor, say 20 years hence, it should be necessary to ask whether it was standardized for physicists or electrotechnicians. Some trifling oversight in specifying the fourth fundamental unit might conceivably lead to such a divergence.

Further Developments

Since this paper was written in August 1935, the following important developments have occurred in relation to the Giorgi system:

1. The Consultative Committee on Electricity (C.C.E.) of the International Committee on Weights and Measures (I.C.W.M.) held meetings in Paris-Sèvres September 24–27, 1935, under the chairmanship of Paul Janet, and made an important report on electrical units and standards, covering also the reply to the I.E.C. inquiry concerning the fourth basic unit for the Giorgi system.
2. The I.C.W.M. held meetings in Paris-Sèvres, October 1–8, 1935, adopting this C.C.E. report and authorizing its general publication. It also issued a brief statement for publication concerning its own activities and aims.
3. The S.U.N. committee under Sir Richard Glazebrook has been actively engaged in securing opinions, by correspondence, as to the fourth basic unit in the Giorgi system for reply to the I.E.C. question on that point. The reply is expected to be published shortly.

Translations of the I.C.W.M. statement and of the C.C.E. report (from the original French texts) are given in Appendixes I and II.

Appendix I—Fourth Report of the Consultative Committee on Electricity (Comité Consultatif D'Electricité) to the International Committee of Weights and Measures

(As translated by the author from the original French text released for publication)

After notices sent out by the International Bureau of Weights and Measures, signed by President Paul Janet, the Consultative Committee on Electricity met in Paris, September 24–27, 1935.

At this fourth session of the committee, the following persons were in attendance:

Mr. Paul Janet, president, Membre de l'Institut de France, director of the Laboratoire Central d'Electriicté.
Mr. Crittenden of the National Bureau of Standards, Washington.
Mr. Sears of the National Physical Laboratory, Teddington.
Mr. Von Steinwehr of the Physikalisch-Technische Reichsanstalt, Berlin.
Mr. Nagaoka, professor emeritus of the University of Tokyo, representing the Electrotechnical Laboratory of Tokyo.
Mr. Lombardi, director of the Electrotechnical Laboratory of the Royal School of Engineers, Rome.
Mr. Guillaume, director of the International Bureau of Weights and Measures.
Mr. Jouaust of the Laboratoire Central d'Electricité, Paris.

In attendance by invitation were:

Mr. MacLellan, Member of the International Committee of Weights and Measures.
Mr. Vigoureux of the National Physical Laboratory.
Mr. Pérard, subdirector of the Bureau International des Poids et Mesures.
Messrs. Romanowski and Roux of the Bureau International des Poids et Mesures.
Mr. Brylinski, president of the French Committee of the I.E.C.
Mr. Kennelly, member of the International Committee of Weights and Measures, prevented from attending by ill health.

On opening the session, President Janet outlined the conditions under which the committee was convened:

The International Committtee, at its last meeting, decided on a recommendation from the Consultative Committee:

"That the Consultative Committee should request the laboratories it represents

to appoint members intended to form a technical subcommittee charged with the duty of making comparisons between their standards of resistance and voltage with all necessary precision, and to assign their values in terms of absolute units."

"That the technical subcommittee should meet at the International Bureau of Weights and Measures in 1935."

"That the decisions of the subcommittee should be examined by the Consultative Committee, before being transmitted to the International Committee."

In conformity with the above decision of the International Committee, Mr. Janet corresponded during the last 3 months of 1934 with the national laboratories represented on the Consultative Committee, requesting each to assign a member to the technical subcommittee, and to propose a date for the meeting of the subcommittee.

The majority of the replies showed that the tasks undertaken in the different laboratories for the determination in absolute units were not far enough advanced to permit of assigning to the regular laboratory standards their values in terms of the absolute system, that under these circumstances the work of the members of the technical subcommittee would be quite ineffective and would be limited to intercomparisons between the standards of the different laboratories, these intercomparisons being effected by conveyance between laboratories; these being either the national physical laboratories, or the International Bureau of Weights and Measures.

Under these conditions, Mr. Janet considered it necessary to postpone the meeting of the technical subcommittee, and to limit operations to a meeting of the Consultative Committee a few days in advance of the International Committee.

The object of the present meeting was therefore to examine the degree of progress in the determination of the absolute units, and the discussion of the precision of the methods employed; so that each member might profit from the experience of his colleagues.

The question of the realization of secondary standards presented itself, especially the nature of the metal to be employed for the construction of secondary standards of the ohm; also the question of the temperature to which they should be referred, might be considered.

In particular, Mr. Janet insisted upon the necessity for fixing at the present session, the date, if possible, for calling the meeting of the technical subcommittee and arranging its program. The fixing of this date was especially called for in a letter received from the Electrotechnical Laboratory of Tokyo.

Mr. Janet pointed out that he had also received information from Mr. Kennelly, that the International Electrotechnical Commission had adopted the mks system, called the Giorgi System, involving the establishment, in addition to the 3 classical fundamental units of length, mass, and time, a fourth fundamental unit, relating to an electrical magnitude, and that the Electrotechnical Commission desired to have the opinion of the Consultative Committee, as to the electrical magnitude which would be desirable to select for this unit.

Mr. Janet considered that, with certain reservations, this question might be placed on the agenda of the Consultative Committee. A report prepared by Mr. Lombardi, a member of the Consultative Committee and also of the International Electrotechnical Commission, might serve as the basis for discussion.

We may now summarize the results attained by the Consultative Committee:

I. Absolute Units

Only 2 laboratories have completed their tasks, namely, the National Bureau of Standards and the National Physical Laboratory, and only one of these investigations has taken the form of a complete publication; i. e., the determination of the ampere, made at the N.B.S. by Messrs. H. and R. Curtis.

The other laboratories (Physikalisch-Technische Reicheanstalt, Electrotechnical Laboratory, Laboratoire Central d'Electricité) have confined themselves to presenting certain notes on the methods employed. The representative of the Electrotechnical Laboratory, Mr. Nagaoka, announced that his establishment would shortly be able to report the result of its measurements. The representatives of the P.T.R. and L.C.E. have been unable to make any similar statement.

(*a*) *Absolute Value of the Unit of Resistance.* The National Bureau of Standards give the following result:

1 international ohm N.B.S. = 1.000 450 absolute ohm

The determination of the absolute ohm had been made at the National Physical Laboratory by 2 methods:

The Lorenz method gave:

1 international ohm N.P.L. = 1.000 50 ± 0.000 02 absolute ohm

By the Campbell method:

1 international ohm N.P.L. = 1.000 47 ± 0.000 02 absolute ohm

In the opinion of the representative of the N.P.L., in view of the precision of the 2 methods, it seemed desirable to take the mean of the 2 above values, and to take as the N.P.L. result:

1 international ohm N.P.L. = 1.000 49 absolute ohm

The above are the only results definitely communicated to the Consultative Committee. The difference of the order of a few millionths between the international N.P.L. ohm and the international N.B.S. ohm, make these results directly comparable.

Moreover, the representative of the Physikalisch-Technische Reichsanstalt observed that certain corrections should be applied to the old measurements of Grueneisen and Giebe, which would lead to the following:

1 international ohm P.T.R. = 1.000 49 absolute ohm

All the above results seem to indicate that one may hope for a knowledge of the ratio of the international ohm to the absolute ohm, when all the laboratories shall have finished their task, to a precision of $\pm 2 \times 10^{-5}$.

(*b*) *Absolute Value of the Unit of Current Strength.* Only 2 laboratories, the N.B.S. and the N.P.L. have finished their researches. The results obtained, expressed in the form used in the reports to the Committee are:

Bureau of Standards

1 international ampere N.B.S. = 0.999 926 absolute ampere

National Physical Laboratory

1 absolute ampere = 1.000 14 international ampere N.P.L.

If account is taken of the difference which exists in the realization of the international ampere in the 2 laboratories, these 2 results differ by 9 hundred-thousandths.

The agreement in the determination of the unit of current strength is thus much less close than in the determination of the unit of resistance.

Discussion of the methods of measurement employed led to an interesting remark from the representative of the P.T.R., on the difficulty of calculating, for the Balance of Lord Rayleigh, the correction due to the volume of the bobbin windings. He observed that in the work of H. and R. Curtis, it was possible to arrive at 2 different values for this correction, according to the method used in measuring the windings.

Reference was made to a recent work of Sir Richard Glazebrook, recently appearing in the *Proceedings* of the Royal Society, *A*, volume 150, 1935, page 487, setting forth the same difficulty.

Mr. Von Steinwehr also mentioned that in order to remedy this difficulty, the Reichsanstalt had given up the method of winding the coils of the Rayleigh balance with wire, in favor of a method of band winding. The necessity of redetermining the radii ratio for these new coils, was one of the reasons for the Reichsanstalt not yet being ready to furnish results.

Mr. Crittenden recognized the importance of Mr. Von Steinwehr's remark, and indicated that at the N.B.S. they had undertaken in their Rayleigh type of electro-dynamometer, the construction of new coils, one made with bands, and the other with but a single layer of wire.

In any case, it would seem that this uncertainty as to a correction does not completely explain the difference between the N.B.S. and the N.P.L.

The committee, while expressing its regrets for the technical difficulties that had hindered the completion of its undertaking, felt glad that the meeting had given rise to a suggestive discussion for all who are engaged in the determination of units to absolute measure.

II. Present Representation of the Units

The value of the international ohm is maintained in the laboratories by means of manganin coils. The resistance of these coils is not constant, but varies slowly as a function of time.

Is it possible to find for the construction of these coils, a metal free from such variations?

A report from the National Physical Laboratory, presented and commented on by Mr. Vigoureux, described the experiments made

in that establishment, for the production of ohm standards in platinum.

Having given the value of the temperature coefficient of resistivity for platinum, these resistances should be used at a practically well determined temperature, that of melting ice.

Mr. Pérard drew the committee's attention to the difficulty which may exist in keeping such resistances precisely at the temperature of melting ice. Mr. Von Steinwehr alluded to the use of the "triple point."

However that may be, many years must elapse before one can be assured of the constancy of these resistances.

The Committee could therefore only felicitate the National Physical Laboratory upon the undertaking of this research.

Questions were asked of the representative of the National Bureau of Standards concerning a new alloy studied in that establishment. Mr. Von Steinwehr remarked that studies had also been made at the P.T.R. on this chromium-gold alloy, and that it had been possible to obtain specimens whose temperature coefficient between 20 and 30 degrees centigrade was almost zero.

But there is still no assurance as to the stability of this alloy, so that it will still be necessary for a long time to come, to construct secondary ohm standards in manganin.

The committee listened also with interest to the account given by Mr. Vigoureux of the method employed at the N.P.L. in the search for standards having a resistance as nearly constant as possible.

A considerable part of the variations manifested by these resistances is attributed to the layer of lacquer which covers them.

At the N.P.L., the manganin wire, rolled under the form which it will occupy on its supporting core, is annealed at 500 degrees, treated with acid, and then placed on its supporting core without being subjected to any mechanical deformation. The layer of lacquer which is intended to protect the wire against the action of the petroleum bath in which it is submerged, is made as thin as possible.

III. Comparison of the Standards From Different Laboratories

Mr. Pérard drew direct attention to the fact that the reference temperature of the units should be standardized. In European countries, this temperature is 20 degrees centigrade; but in the United States and Japan, it is 25 degrees centigrade.

Mr. Pérard requested that this temperature should be fixed, and proposed 20 degrees centigrade.

Mr. Crittenden (United States), and Mr. Nagaoka (Japan), pointed out that in their countries, the temperature was close to 25 degrees centigrade. They indicated the difficulty there would be in keeping the standards at a temperature lower than the ambient temperature. Nevertheless they agreed to the temperature of 20 degrees centigrade for standards intended for international comparison.

This agreement was recorded in a resolution. (See appended Resolution 1, at the end of the report.)

The transport of standards from one laboratory to another, involves certain difficulties.

In a note sent to the committee, the Electrotechnical Laboratory of Tokyo described the boxes which it utilized for the transport of standard cells.

Certain laboratory representatives pointed out, however, the difficulties that customhouse administrations had given them, and asked whether it would not be possible to use the consular bag (*valise diplomatique*) for standards intended for international comparison.

It was decided to ask the president of the International Committee of Weights and Measures to take the steps necessary for having standards intended for international comparison accepted for transport in consular bags (Resolution 2).

Messrs. Pérard, Romanowski, and Roux reported on comparisons made at the International Bureau of Weights and Measures, of standards of resistance and of electromotive force from laboratories represented in the membership of the Committee.

The results were rendered comparable by taking for the mean value of the units, the arithmetrical mean of the units in the 6 laboratories, and by indicating the difference between the unit of each laboratory and this mean.

The representative of the Laboratoire Central, Mr. Jouaust, stated that the units of the establishment to which he belonged differed the most, particularly as regards the mean value of the resistance units.

The cause of these divergences of 7 hundred-thousandths had not, of course, escaped him. In view of accidental error, he asserted that the Laboratoire Central intends to modify the value of its standards, so as to bring them into agreement with those of the other 5 laboratories.

By employing only these 5 values, in the establishment of the average, the difference between the resistance units of these laboratories and their average would then appear as follows (at the date of March 15, 1935):

P.T.R.	+ 9.8 millionths
N.B.S.	− 5.5 millionths
N.P.L.	− 3.6 millionths
E.T.L.	−11.2 millionths
U.R.S.S.	+10.6 millionths

The above differences are small; but nevertheless it may be necessary to take them into account in certain cases. In consequence, Mr. Jouaust asked if the different laboratories could not follow the example set by the Laboratoire Central and modify the value of their unit for the purpose of standardization.

This proposition met with some opposition. The values of the units being due to be changed shortly, to be expressed in absolute units, certain members of the committee considered that it would be preferable to await that date before proceeding to the proposed standardization.

Others did not consider themselves authorized to accept any change in a standard of their country, however small.

Nevertheless, the Committee concluded by adopting resolution 4.

IV. Fixing the Date of Meeting for the Technical Subcommittee

President Janet renewed attention to the agreement arrived at on this matter by the Consultative Committee at its last session.

He insisted on the necessity of fixing this date for the subcommittee, pointing out that Japan proposed that this date should be set between June and December 1936. He also asked the committee to specify the duties to be assigned to the subcommittee.

All the members agreed that the 2 parts of the program indicated for the subcommittee still hold, and that the comparisons appearing in its program were only set up for the purpose of immediately fixing the values in absolute units.

The 2 functions of the subcommittee are inseparable.

It was unanimously agreed that it would only be possible to convene the subcommittee after a sufficient lapse of time to enable its members to carry out the comparisons themselves. Only certain ones could be effected. The principal task of the subcommittee will therefore be to discuss the values found and assign weights to them.

The setting of the date for the subcommittee gave rise to some remarks from Mr. Von Steinwehr, who wished to leave the date to the president with power to fix it when he judged the work of the laboratories was sufficiently far advanced. It was finally decided to set the date at the beginning of the year 1937 (Resolution 3).

V. Examination of the Question Raised by the International Electrotechnical Commission Relative to the MKS System

In opening the meeting, President Janet explained the conditions under which the matter was laid before the Consultative Committee.

The Consultative Committee was appointed to inform the International Committee of Weights and Measures on questions relating to standards in the electrical field and in adjacent subjects.

In giving advice to any other organization, it would be going outside the limits assigned to it.

The International Electrotechnical Commission should therefore have addressed its question to the International Committee.

But it is almost self evident that the International Committee would wish to have the opinion of the Consultative Committee. But since the session of the latter preceded that of the International Committee, if the question had been transmitted directly to the International Committee, it would have been impossible to bring it before the Consulting Committee without a rather long delay.

Under these conditions, with the approval of Mr. Volterra, president of the International Committee, Mr. Janet considered himself justified in placing the matter on the agenda of the Consultative Committee, it being understood that any opinion reached would be forwarded to the International Committee, which is alone competent to reply. The president asked the members of the Consultative Committee if they approved of the procedure he suggested.

This procedure was unanimously adopted.

On the other hand, the Consultative Committee forwarded to the International Committee a series of proposals anonymously received,

relating to questions of notation and nomenclature. The Committee then proceeded to an examination of the question presented by the I.E.C.

The question is set forth in a communication from Mr. Lombardi. Moreover, the members of the Committee were in possession of various documents on the subject, emanating from Sir Richard Glazebrook and from Messrs. Kennelly, Campbell, Giorgi, Emde, Wallot, and Bennett.

Mr. Lombardi presented his memoir with comments. From this presentation, it appears that the original form of the mks system, as given by Mr. Giorgi and strongly endorsed by Mr. Campbell, should comprise 4 fundamental units of which only 3, the meter, the kilogram, and the second were originally indicated. The fourth should now be fixed in such a manner as to permit of incorporation into a coherent system the well-known practical units of current, electric quantity, electromotive force, capacitance, resistance, inductance, and magnetic flux. Messrs. Giorgi and Campbell have proposed the international ohm for the fourth unit, in view of the large number of its existing standards; but their proposal could not be entertained by the International Electrotechnical Commission after the decision by the International Commission of Weights and Measures, ratified by the General Conference of 1933, to substitute the absolute system for the international system.

The I.E.C. did not consider that it could adopt the permeability of space unchanged since it has not the essential character of a unit and is not susceptible of being embodied in a standard, but assumes different values in the rationalized and nonrationalized mks system between which no definite choice has yet been made, by international agreement. For this reason the I.E.C. considered that the choice should be limited to the 7 practical units above referred to, which from a theoretical standpoint are equivalent in this regard, and which being dependent on the absolute cgs system are necessarily related to the unity value of space permeability. With reference to the ease of construction and comparison of standards, Mr. Lombardi has shown in his paper some preference for the unit of resistance without losing sight of the fact that certain among the other units might possess similar advantages, and that the creation of a primary standard could only be effected to an approximation quite sufficient for practice without possessing the absolute invariability attributable to the other fundamental units of length, mass, and time selected arbitrarily and represented to some extent conventionally by concrete standards maintained at Breteuil.

Mr. Janet drew the attention of the committee to the opinion of Sir Richard Glazebrook, president of the S.U.N. commission, definitely expressing the opinion that the fourth unit should be the magnetic permeability of vacuum, to which in the mks system would be given the value 10^{-7}; so that the electrical units of the mks system would be the practical units of the absolute system. He also read a letter from Sir Joseph Petavel, stating that the executive committee of the National Physical Laboratory supported this proposal.

Mr. Sears observed that in making a selection of a fourth unit at the request of the I.E.C., the committee accepted by implication the mks system, so far as concerns the electrical units. But the mks system is essentially the same as the cgs system, there being only a difference of powers of 10.

Therefore the committee should not assign any superiority of choice, and should manifest no preference.

By a large majority, the committee decided for a selection of the permeability of space. Mr. Nagaoka, representing Japan, abstained, and Mr. Crittenden stated that his opinion was a personal one.

On the observation by Mr. Lombardi, that the solution indicated by the committee was aside from that sought by the I.E.C., and that the committee should only select from among the 7 units already referred to, the president consulted the committee anew under the following form: If the solution of fixing the value of space permeability were set aside, which electrical unit would you propose to introduce for definition into the mks system?

By the feeble majority of 4 votes against 3 and 1 abstention, the committee declared for the ohm, after a protest from one of the members at the limitation imposed on the opinion asked for, in the form of the question raised by the I.E.C., and finally a draft opinion drawn up by Messrs. Pérard and Jouaust, appearing at the end of the present report, was approved by the committee. (Resolution *5a*.)

The day after the above discussion, Mr. Sears read a note which he had drawn up. To a question from one of the members, he explained that the values given in paragraph 5 below only represent an ideal series of derived units from among a number of possibilities, and that this plan should not be taken as definitely assigning the procedure to be followed in the practical development of standards.

He showed by way of example, the possibility of deriving, practically, all of the electrical units from the construction of an inductance.

The proposals of Mr. Sears, which are not in opposition to the preceding decisions of the committee, were much appreciated by the members, who expressed the opinion that Mr. Sears's note, whose text is appended (Resolution *5b*) should be transmitted to the International Committee, along with the opinions previously expressed.

VI. Visits

The members of the committee were invited by Mr. Janet to visit the rooms of the Laboratoire Central d'Electricité, where researches are made on electrical units, and to examine the apparatus in course of construction for the determination of the ohm in absolute measure.

Before concluding, the committee voted its thanks to Mr. Janet for the manner in which he had directed the discussions, and to Mr. Perard for his care in securing the successful operation of the sessions, and especially for assuring the advance distribution of the documents needed in the committee's work. Mr. Jouaust, of the Laboratoire Central d'Electricité, was appointed secretary for the session of 1935.

Resolutions Voted by the Consultative Committee on Electricity in Its Session of September 1935

Resolution 1. For international comparison of electrical standards, the values reported will be those corresponding to a temperature of 20 degrees centigrade, unless an exception is justified.

Resolution 2. The Consultative Committee requests the International Committee to pass a resolution, which should be transmitted to the interested governments, to the end that delicate instruments, and especially electrical standards, may be transported through the medium of the consular bag, (*valise diplomatique*), so as to avoid opening at customhouses, full liberty being, however, allowed to those laboratories that may prefer some other mode of conveyance

Resolution 3. The Consultative Committee decides to fix at first the meeting of the technical subcommittee at the beginning of the year 1937. The Consultative Committee will then meet in the course of that year, a few days before the regular session of the International Committee of Weights and Measures.

Resolution 4. The Consultative Committee on Electricity records with satisfaction the decision taken by the Laboratoire Central d'Electricité, to modify forthwith the magnitude of its unit of electrical resistance, as well as that of its unit of electromotive force, by some few hundred-thousandths, in order to bring them into agreement respectively with the corresponding averages of the values for these units as they are maintained in the 5 other great national laboratories: The Physikalisch Technische Reichsanstalt, the National Physical Laboratory, the National Bureau of Standards, the Electrotechnical Laboratory of Tokyo, and the Metrological Institute of the U.R.S.S.

The Consultative Committee: Considering in that case how very small would be the deviations of the ohm unit and volt unit in each of the 5 laboratories from the respective averages above mentioned, the greatest deviation for either the ohm or volt scarcely reaching 11 millionths; and considering the great importance which would be presented by unification of electrical units in the near future in all countries; suggests to the different laboratories, each acting for itself, and as soon as an opportunity may be offered, to adopt for the magnitude of the ohm and for the magnitude of the volt, respectively, the values defined by the above-mentioned averages.

Resolution 5a. The Consultative Committee on Electricity, upon a question from the International Electrotechnical Commission, relating to the most suitable choice of an electric unit in the mks system, desires first to observe, that according to the Rules of its Constitution, it can only communicate with the International Committee of Weights and Measures. Nevertheless, with the consent of the president of the International Committee, it decided to consider the question presented, the opinion reached being reported to that committee, which alone is competent to make reply.

The Consultative Committee first desires to state that a distinct majority of its members present expressed the opinion that the link between the mechanical and electrical units should be effected by

assigning the value 10^{-7} in an unrationalized mks system, and $4\pi \cdot 10^{-7}$ in a rationalized system, to what is commonly called the permeability of space.

As to the remark that the form in which the question was put limited the choice to the 7 practical units, coulomb, ampere, volt, ohm, henry, farad and weber, the committee unanimously considered that the choice should only fall either on the ampere, defined as 10^{-1} of the cgs electromagnetic unit, or on the ohm, defined as 10^9 cgs electromagnetic units of resistance, these 2 magnitudes, corresponding to the values of 10^{-7} or $4\pi \cdot 10^{-7}$ for space permeability, as above mentioned.

By vote, the committee pronounced in favor of the ohm against the ampere by the small majority of 4 against 3, and 1 abstention.

Resolution 5b. In the following session, Mr. Sears presented to the Consultative Committee the following document:*

Note presented by Mr. Sears:

1. The electrical unit magnitudes of the system sanctioned by the General Conference in 1933, are identical with those of the practical units derived from the classical cgs system of Maxwell.
2. These systems are based essentially on the conception of a constant value for space permeability, this value being in the Maxwell system numerically equal to 1. For the mks system unrationalized, this permeability would have the value 10^{-7}, and for the mks system rationalized, the value $4\pi \cdot 10^{-7}$. In each of these systems the coefficient A^* is taken as a purely numerical constant, to which is assigned the value unity so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the General Conference of 1933.
3. The various electrical units can all be derived from this conception, by means of equations representing physical laws, and with suitably selected constants. In principle, no one of these units has priority over the rest.
4. The definitions adopted for the principal electromagnetic units might be the following:

(*a*) *Ampere.* The ampere is the constant current which, maintained in 2 parallel rectilinear conductors of infinite length, separated by a distance of 1 meter, produces between these conductors a force equal to 2×10^{-7} mks units of force per meter of length.

(*b*) *Coulomb.* The coulomb is the quantity of electricity transported each second by a current of one ampere.

(*c*) *Volt.* The volt is the difference of electrical potential between 2 points of a conducting wire carrying a constant current of one ampere, when the power dissipated between these points is equal to one mks unit of power (watt).

(*d*) *Ohm.* The ohm is the electrical resistance between 2 points of a conductor, when a constant difference of potential of one volt, applied between these points, produces in the conductor a current of one ampere, the conductor not being the seat of an electromotive force.

(*e*) *Weber.* The weber is the magnetic flux which, traversing a circuit of a single turn, would produce an electromotive force of one volt, if brought to zero in one second with uniform diminution.

(*f*) *Henry.* The henry is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current traversing the circuit varies uniformly at the rate of one ampere per second.

(*g*) *Farad.* The farad is the electrical capacitance of a capacitor between the armatures of which appears an electrical difference of potential of one volt, when charged with one coulomb of electric quantity.

5. These units may be derived as follows:

Ampere	I	Ampere	I
Coulomb	Q	Ampere-second	IT
Volt	E	Watt per ampere	PI^{-1}
Ohm	R	Volt per ampere	EI^{-1}
Weber		Volt-second	ET
Henry	L	Volt-second per ampere	$EI^{-1}T$
Farad	C	Ampere-second per volt	$E^{-1}IT$

6. For the regular practice of laboratory measurements, at least 2 primary standards of reference are needed and may be conveniently chosen among the various units. The 2 reference standards should be the ohm and volt, the former being produced under the form of coils and the latter under the form of Weston cells.
7. For theoretical questions, such as the dimensional equations connecting the various units, the most convenient unit as a starting point for the derivation of the entire system of electromagnetic units appears to be the ampere, which is directly connected by simple relations not only with the fundamental base of the system; but also with the other electric and magnetic magnitudes, and which, moreover, has the advantage of eliminating fractional powers from the dimensional equations. In this respect, the ampere should be preferred as the fourth unit, in order to complete the mks system of electromagnetic units.

This document met with a unanimously favorable reception in the Consultative Committee, which decided to transmit it to the International Committee without, however, finding it necessary to alter its vote of the previous day.

* In the course of the meetings of the International Committee of Weights and Measures, Mr. Sears asked permission to insert certain additions at the head of this note in conformity with suggestions made to him by Sir Richard Glazebrook, these additions not affecting the general meaning of the note. The following paragraph has therefore been added:

Electromagnetic theory leads to the relation

$$A^2 = \mu_0 \times k_0 \times c^2$$

between the 4 quantities there appearing. Of these,
c is the velocity of the propagation of electromagnetic waves in vacuum
μ_0 is the magnetic permeability of a vacuum
k_0 is the permittivity of a vacuum
A is a constant coefficient
In order to have a theoretically complete system of electrical units, it is necessary to assign independent values to 2 of the 3 quantities A, μ_0, and k_0. The third will then be determined by the above relation. In each of these systems the coefficient A is taken as a purely numerical constant to which is assigned the value given above so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the general conference of 1933.

Appendix II—Intended Substitution of the Practical Absolute System of Electrical Units for the Existing International System

The following information (as translated from the original French text) was approved for general publication by the International Committee of Weights and Measures at its meeting in October 1935, at Sevres, France.

1. In accordance with the authority and responsibility placed upon it by the General Conference of Weights and Measures in 1933, the International Committee of Weights and Measures has decided that the actual substitution of the absolute system of electrical units for the international system shall take place on January 1, 1940.
2. In collaboration with the national physical laboratories, the committee is actively engaged in establishing the ratios between the international units and the corresponding practical absolute units.
3. The committee directs attention to the fact that it is not at all necessary for any existing electrical standard to be altered or modified with a view to making its actual value conform with the new units. For the majority of engineering applications, the old values of the international standards will be sufficiently close to the new for no change, even of a numerical nature, to be required. If for any special reason a higher precision is necessary, numerical corrections can always be applied.
4. The following table gives a provisional list of the ratios of the international units to the corresponding practical absolute units, taken to the fourth decimal place. Since differences affecting the fifth decimal place exist between the standards of the international units held by the various national laboratories and also because all the laboratories which have undertaken determinations of the values of their standards in absolute measure have not yet obtained final results, the committee does not consider it desirable for the present to seek a higher precision. At the same time, it hopes that it will be possible to extend the table of these ratios, with a close approximation to the fifth decimal place, well before the date fixed for the actual substitution of the practical absolute system for the international system.

Table

1	Ampere	international	=	0.999 9	Ampere	absolute
1	Coulomb	international	=	0.999 9	Coulomb	absolute
1	Ohm	international	=	1.000 5	Ohm	absolute
1	Volt	international	=	1.000 4	Volt	absolute
1	Henry	international	=	1.000 5	Henry	absolute
1	Farad	international	=	0.999 5	Farad	absolute
1	Weber	international	=	1.000 4	Weber	absolute
1	Watt	international	=	1.000 3	Watt	absolute
1	Joule	international	=	1.000 3	Joule	absolute

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